DU[illegible]RY
MA[illegible]OOL
MON[illegible]6008

NAVAL POSTGRADUATE SCHOOL
Monterey, California

C4152

THESIS

BASIC INVENTORY MANAGEMENT TECHNIQUES
FOR THE REPUBLIC OF CHINA

by

Cheng, Cheng-Wen

December, 1989

Thesis Advisor: Dan Trietsch

Approved for public release; distribution is unlimited.

T247182

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School 6b OFFICE SYMBOL (If applicable) Code 54	7a NAME OF MONITORING ORGANIZATION Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5100	7b ADDRESS (City, State, and ZIP Code) Monterey, California 93943-5100
8a NAME OF FUNDING / SPONSORING ORGANIZATION 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
BASIC INVENTORY MANAGEMENT TECHNIQUES FOR THE REPUBLIC OF CHINA NAVY

12 PERSONAL AUTHOR(S)
Cheng Cheng-Wen

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM _____ TO _____	1989 December	68

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect th4 official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
			Inventory Management

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Lacking further development of mathematical inventory models and well utilized automated records, the Republic of China (ROC) Naval supply system cannot operate efficiently and effectively. The constraints of budget, foreign exchange and unpredictable procurement lead times have resulted in an inventory level higher than optimal. However, the inventory management process and overall supply support performance could be improved using theoretical and practical approaches. The three objectives of this thesis are: to analyze the ROC Navy's inventory models; suggest possible improvements; and recommend appropriate changes. The desired benefits would be to improve the existing inventory management system, and relieve inventory control problems in the ROC Navy.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	UNCLASSIFIED
22a NAME OF RESPONSIBLE INDIVIDUAL Dan Trietsch	22b TELEPHONE (Include Area Code) 646-2456 / 22c OFFICE SYMBOL 54TR

DD Form 1473, JUN 86 *Previous editions are obsolete* SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603

Approved for public release; distribution is unlimited.

Basic Inventory Management Techniques For The Republic Of China

by

Cheng, Cheng-Wen
Lieutenant, Republic of China Navy
B.S., National Defense Management School, Republic of China

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
December 1989

ABSTRACT

Lacking further development of mathematical inventory models and well utilized automated records, the Republic of China (ROC) Naval supply system cannot operate efficiently and effectively. The constraints of budget, foreign exchange and unpredictable procurement lead times have resulted in an inventory level higher than optimal. However, the inventory management process and overall supply support performance could be improved using theoretical and practical approaches. The three objectives of this thesis are : to analyze the ROC Navy's inventory models; suggest possible improvements; and recommend appropriate changes. The desired benefits would be to improve the existing inventory management system, and relieve inventory control problems in the ROC Navy.

T10.13
C4:52
C.1

TABLE OF CONTENTS

I. INTRODUCTION 1

A. BACKGROUND 1

B. FUNCTIONS OF INVENTORY 1

C. PURPOSE OF INVENTORY MANAGEMENT 2

D. EVOLUTION OF INVENTORY MANAGEMENT 3

E. PURPOSE AND SCOPE 4

F. PREVIEW 5

II. INVENTORY MANAGEMENT IN THE ROC NAVY 6

A. SUPPLY SYSTEM OVERVIEW 6

B. INVENTORY MANAGEMENT OBJECTIVES AND APPLICATION 8

C. INVENTORY TERMINOLOGIES AND MODELS 10

D. SUMMARY 13

III. BASIC INVENTORY MODELS THEORY 15

A. INVENTORY PROBLEMS CLASSIFICATION 15

B. INVENTORY COSTS 17

C. ECONOMIC ORDER QUANTITY (EOQ) MODEL 18

D. STATISTICAL CONSIDERATIONS 20

E. SAFETY STOCK 20

F. PROBABILITY OF STOCKOUT 21
G. SHORTAGE COSTS EXPRESSION 21
H. SERVICE LEVEL 22
I. REORDER DECISION 24

IV. FORECASTING 33
A. INTRODUCTION 33
B. FORECAST MODELS 33
C. FORECAST ERROR 38
D. FORECAST DEMAND AND MAD_n 39
E. FORECAST PROCUREMENT LEAD TIME(PCLT) AND MAD_{LT} . . 41
F. COMPUTE THE CONSTRAINED Q AND R 42

V. PERFORMANCE MEASURES OF EFFECTIVENESS (MOEs) 47
A. INTRODUCTION 47
B. GROSS EFFECTIVENESS AND NET EFFECTIVENESS 47
C. SYSTEM MATERIAL AVAILABILITY (SMA) 48
D. OPERATIONAL AVAILABILITY (Ao) 48
E. MEAN SUPPLY RESPONSE TIME (MSRT) 50
F. AVERAGE CUSTOMER WAIT TIME (ACWT) 50

VI. CONCLUSIONS AND RECOMMENDATIONS 54
A. SUMMARY 54

B. CONCLUSIONS 55
C. RECOMMENDATIONS 56

LIST OF ABBRIVIATIONS. 60
LIST OF REFERENCES 63

I. INTRODUCTION

A. BACKGROUND

In 1973, the Republic of China (ROC)'s Navy adopted a computer system to help with inventory management. Since then, the supply system and the logistic availability has improved significantly. Unfortunately, lacking further development of mathematical inventory models and well utilized automated records, the computer system cannot be operated efficiently. In addition, the constraints of foreign exchange and unpredictable procurement lead times have resulted in an inventory level higher than optimal. With higher inventory levels supply personnel is more confident about being able to satisfy demand. Top command is becoming more aware of the defense budget constraints and how inventory management relates to overall performance of the Naval service. Thus, advanced inventory techniques have to be learned by each member of the ROC Navy Supply Corp in order to analyze and to control the inventory problems.

B. FUNCTIONS OF INVENTORY

Inventories are those items held by an organization for future needs. It includes raw materials, work-in process, by-products, and final products. Inventory exists because supply and demand cannot be perfectly matched. Studies show that in the private sector 15-90% of the total assets is as inventory and in the public sector the figure is at least 25%. The existence of inventories can be explained by four functional

factors: time, discontinuity, uncertainty, and economy. To quote Principles of Inventory & Material Management [Ref.1]:

- The *time factor* involves the long process of production and distribution required before goods reach the final consumer. Profitability can be enhanced by having products available immediately or within a reasonable time.

- The *discontinuity factor* permits the organization to schedule many operations at a more desirable performance level than if they were integrated dependently (purchasing, distributing, warehousing, manufacturing...).

- The *uncertainty factor* concerns unforseen events that modify the original plans of the organization some protection from unanticipated or unplanned occurrences.

- The *economy factor* allows the organization to take advantage of cost reduction alternatives. It enables an organization to purchase on produce items in economic quantities.

C. PURPOSE OF INVENTORY MANAGEMENT

Due to the severe competition among business organizations and the rapid growth of personnel expenses and material costs, inventory management has become one of the major organizational functions, along with design, finance, manufacturing, and marketing. Inventory management must constantly consider storage capacity, material handling equipment, suppliers, and acquisition difficulties. With increased technology and specialization, the quantity and complexity of input becomes very difficult to handle and requires more and more advanced materials management skills. The goals of an organization are to maximize profits, minimize expenses, use the capital efficiently, and maintain smooth business operations. In contrast, the major goal of the

military is to maximize the supply availability of combat readiness under budget constraints.

The purposes of inventory management are summarized as:

- To minimize inventory investment
- To use capital efficiently
- To maximize customer service
- To keep reasonable inventory level and to assure sound business operations
- To buy materials at economic lot sizes and low unit cost
- To predict future needs
- To insure high inventory turnover rate
- To maintain consistent quality
- To promote positive supplier relations
- To reduce the procurement lead time as possible
- To utilize storage capacity efficiently
- To avoid obsolescence

D. EVOLUTION OF INVENTORY MANAGEMENT

Inventory control is a science-based art of controlling the amount of stock held to meet demands economically [Ref. 2]. With in the last four decades, Scientific inventory control has experienced a rapid growth in the use of mathematical models to determine the rules of operation for inventory systems.

Inventory was previously considered as personal "fortune" by merchants. When the Great Depression broke the world's economy in 1929, inventory became a nightmare to the merchants. As a result, the Economic Order Quantity (EOQ) method

came into its own and was widely practiced. During World War II, military operations research groups in the United States & Great Britain developed the "minimum losses" concept in inventory management for combat situations. After that, the management sciences, statistics theory, and operations research fields emerged and focused on the stochastic nature, that is, the risk and uncertainty of inventory problems. After the 1960's, the improvement of computer-oriented technologies eased the application of queueing theory, dynamic programming, and simulation techniques of inventory problems.

In most nations, the military tends to be the single largest consumer. Military supply support inventory usually plays a very important role (approximately 20-30%), second only to the weapon system itself in the total defense budget. Holding too much inventory ties up too large a portion of a nation's economy and can become a huge burden; holding too little inventory, on the other hand, will not provide sufficient support, causing a dangerous situation in terms of combat readiness.

The United States Navy has devoted much effort to operations research in developing inventory models, and has achieved extensive and progressive improvements. This author has examined these models and experiences in order to develop recommendations for improving the inventory management in the ROC Navy.

E. PURPOSE AND SCOPE

The introduction of scientific inventory management techniques should improve the present concepts and methodologies used by the ROC Navy for inventory control management. This should provide a more accurate inventory level which will

minimize total annual inventory costs while maximizing the effectiveness of the logistic support.

Because the inventory requirements are different from one type of vessel to another, it is important that we apply the appropriate inventory model to meet the specific requirements of each vessel. This thesis will describe some useful inventory management techniques which are currently used by the U.S. Navy. Implementation of these techniques after certain modifications would improve the management of inventory control in the ROC Navy. For this purpose, the approach used by this paper is based on those inventory management concepts and models which are applicable to the ROC Navy.

F. PREVIEW

Chapter II describes the supply system, inventory management concepts, terminology and basic inventory models presently used in the ROC Navy. Chapter III analyzes the best scholastic and operational inventory models and concepts currently used in the U.S.. Chapter IV discusses forecasting methodology and its applications. Chapter V introduces the measures of effectiveness in inventory management in the U.S. Navy. Chapter VI contains a summary and recommendations for the ROC Navy.

II. INVENTORY MANAGEMENT IN THE ROC NAVY

A. SUPPLY SYSTEM OVERVIEW

In accordance with the long term cooperation with the U.S. Government, most of the weapon systems and equipment in the ROC are purchased from the United States. Also the ROC's current military structure and the operating procedures are similar to the U.S.'s. The supply system provides the supplies and services to satisfy customer needs, during peacetime and wartime, and maintains the Navy's personnel and equipment operating at an acceptable level. The structure of the Naval Supply System Command Headquarters (NAVSUP) is shown in Figure 1.

1. Naval Supply System Command (NAVSUP):

The ROC NAVSUP executes those technical guidance & logistic policies received from the Naval General Headquarters, and then provides supply and technical support policies for material assigned to Navy activities. Supply support includes procurement, storage, distribution, transportation, quality control, and disposal.

- Procurement: Purchasing materials and equipment.
- Storage: Storing materials safely and conveniently.
- Distribution: Relocating available materials as needed.
- Transportation: Shipping materials properly and safely to the destination.
- Quality control: Ensuring inventory accuracy and quality.
- Disposal: Identifying and removing useless inventories properly.

Technical support includes cataloging, identification, requirement determination, repair management, and war reserve planning.

- Cataloging: Collecting, storing and publishing all technical information regarding all equipment and parts.
- Identification: Identifying equipment and parts.
- Requirement determination: Determining the quantity of each item to procure.
- Repair management: Establishing standards and schedule for repairable items.
- War reserve planning: Contributing to mobilization and combat strategies.

The objectives of the inventory management in NAVSUP are:

- To maintain the appropriate inventory level to support weapon systems and equipment for combat readiness.
- To achieve a balance between acquisitions and requirements.
- To maximize the supply effectiveness under budget constraints.
- To adjust and redistribute inventory excesses and reduce shortages among military forces.

2. Inventory Control Point (ICP):

The Inventory Control Point (ICP) is one of the most important functions of NAVSUP, because it controls both fleet and aircraft inventories. The responsibilities of the ICP are:

a. Life cycle weapons support

b. Allowance and load lists determination

c. Provisioning

d. Performing value engineering and item standardization studies

e. Computer operations

* Data Processing
* Computer files management
* Range and depth computations
* Inactive and shortage items lists

f. Procurement plans

* Annual material procurement plans
* Contingency requirements
* Typical program support

g. Information sharing & redistribution of inventories among military forces

3. **Supply Center (SC):**

The main mission of a Supply Center (SC) in the ROC Navy is the geographical and physical distribution of materials including these five responsibilities: receiving, storing, issuing, shipping, and reporting accountability records to the ICP.

To summarize the discussion of the structure and responsibilities of NAVSUP, the purpose of the supply system is not only to supply items but more to keep equipment and weapon systems operating.

B. INVENTORY MANAGEMENT OBJECTIVES AND APPLICATION

1. ABC-ANALYSIS MANAGEMENT

The concept of the ABC-Analysis is to focus management concern on expensive and the most frequently consumed items. Often, 10% of the expensive items equals more than 75% of the total inventory dollar value and only 15% of inventories are frequently used. Therefore, we must pay more attention to these items in an attempt to save money for the Navy. Inventory managers need to focus on insurance items, long lead time items, and the short shelf-life products as well.

2. COST CONTROL

To reduce the holding cost, processing cost, procurement cost, insurance, handling expense, foreign exchange rate, and economic fluctuation as possible and to gather information and bids from outside vendors for providing a broader source of materials replenishment alternative. For some common items among the Armed Forces, the centralized purchasing process provides a great deal of discount which will reduce the unit price and the total costs.

3. FINANCIAL ADJUSTMENT

Use previous experience and intuition to maintain an appropriate inventory level for each item and to meet requirements under budget constraints.

4. MANAGEMENT CONTROL

To enhance supply management by:

- Ordering early to insure sufficient supplies during lead time.
- Avoiding duplication and/or exhaustion for each item.
- Staying abreast with the global economic change and the information about suppliers.

- Maintaining the technical information for weapon systems or parts and the contract files.
- Establishing a real time on-line inventory control net work among SPCC, ICP, and SP, and keeping good track of inventory records.

C. INVENTORY TERMINOLOGIES AND MODELS

The inventories are differentiated into two major categories: principle items and secondary items.

Principle items: Principle items are final products, weapon systems, or major components that are specifically designated for operation or combat purpose,including aircraft, ships, tanks and radar.

Secondary Items: Items that are managed by the ICP for supporting equipment and weapon systems and their major components. Basically, this includes consumable items and repairable items.

Consumable Items: Consumable items are not repairable and lose value or function after use.

Repairable Items: Items which can be reused after repair; these are usually more expensive than consumable items.

Insurance Items: Those items which are carried for preventing accidents, abnormal equipment failures or serious damage to operating capability of the weapon system.

By frequency of demand are distinguished as:

High Demand Based Items (ranked 1): Annual demand >= 20 units.

Middle Demand Based Items (ranked 2): Annual demand < 20 but >= 4 units.

Low Demand Based Items (ranked 3): Annual demand < 4 units.

Non Demand Based Items (ranked 4): Items that should be retained for possible future need or for similar programs.

By unit price and annual cost are grouped as:

High Cost Items: Unit price >= $400 (in U.S. Dollars) and annual cost >= $5000.

Middle Cost Items: Unit price >= $15 and annual cost >= $1500.

Low Cost Items: Those items which are not included in the first two categories.

For the automated computation purpose, each item is assigned by different code(s).

Essentiality codes: Demands for material in support of special programs or weapon systems, assign "1" for the failure which would render the system inoperable; "5" for the personnel safety considerations.

Source Codes: There are three sources from which items are purchased. Foreign Military Sale (FMS), International Trade (INT), and Domestic (DOM).

Mark Code: Categorized from A to I.

(Sources)	FMS	INT	DOM
(Price)			
High	A	B	C
Middle	D	E	F
Low	G	H	I

Forecasted Demand (FD): The forecasted annual demand for the next year.

Safety Level (SL): Extra inventory kept on hand as a cushion against stockout.

Operating Level (OL): Inventory stocks for normal operation requirements.

Lead Time (LT): The time period from originating paper work to actual receipt of the materials.

ASSETS

Inventory on hand (OH)

Inventory on order (OO)

[On hand repairable items + Undergoing repair] * survival rate

(RI+UR)*SR

REQUIREMENTS

Recurring demand reorder level (D)

Procurement lead time demand (PCLT)

Back-ordered requisitions (BO)

Due out to requisitions, redistributions, disposal (RRD)

War Reserve Material Requirement (WRMR)

When Assets < Requirements, a purchase is initiated for that item. That is:

$$OH + OO + (RI + UR) * SR - [D + PCLT + BO + RRD + WRMR] < 0,$$

and the requirement determination formulas are:

$$D_n = (D_{n-1} + D_{n-2} + \ldots + D_{n-24}) / 24$$

(Moving average of monthly demand in last 2 years)

$$F = D_n * (SL + OL + LT) / 360$$

$$R = SL + LT \quad \text{(reorder point)}$$

Pre-determined inventory level for each requirement:

Mark Code	A	B	C	D	E	F	G	H	I
* S L	30	30	30	30	30	30	30	30	30
* O L	60	60	60	90	90	90	150	150	150
* L T	360	360	105	360	360	105	360	360	105

* Based on the experimental data (in days).

For Example: Given,

D_n = 10 , Mark Code: A Item

F = 10 * (30 + 60 + 360) / 360 = 12.5 ~ 13 (units)

R = 10 * (30 + 60) / 360 = 2.5 ~ 3 (units)

D. SUMMARY

Many problems arise from:

1. Using pre-determined inventory level to fit the variety of requirements and unpredictable procurement lead times. Therefore, most of the time, items and the quantity of each item prepared in advance cannot meet actual demands.

2. Not considering economic order quantities (EOQ).

3. Inability to monitor trending signals and reacting slowly to those signals.

4. Lack of the measures of effectiveness concepts (MOE) to improve the total supply availability & readiness.

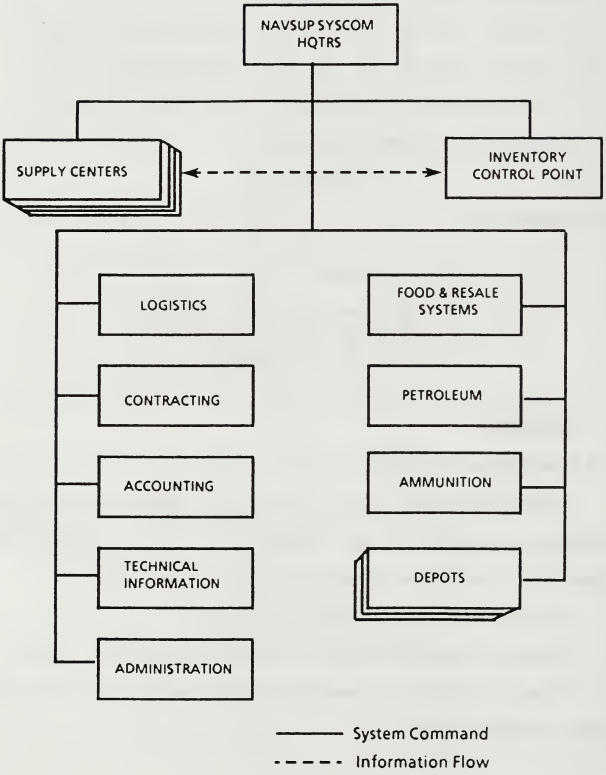


Figure 1 NAVAL SUPPLY SYSTEM COMMAND (ROC)

III. BASIC INVENTORY MODELS THEORY

A. INVENTORY PROBLEMS CLASSIFICATION

Inventory problems can be classified in many ways. Figure 2 displays the inventory problem classification with the following subdivisions: [Ref.1]

1. Repetitiveness
   a. Single order- nonrecurring demand
   b. Repeat order- recurring demand

2. Supply source
   a. Outside supply
   b. Inside supply

3. Type of demand
   a. Constant or variable demand
   b. Independent or dependent demand

4. Type of lead time
   a. Constant lead time
   b. Variable lead time

5. Inventory system
   a. Perpetual review
   b. Periodic review
   c. Material requirements planning (MRP)
   d. Distribution requirements planning (DRP)
   e. Single order quantity

Based on reasonable assumptions, we can use mathematical models to simplify and approximate the real world inventory situation, as this list suggests: forecast future demand, define decision variables, and define objective functions and constraints. In addition, the models can represent the essence of a problem and be uses to state the problem formally.

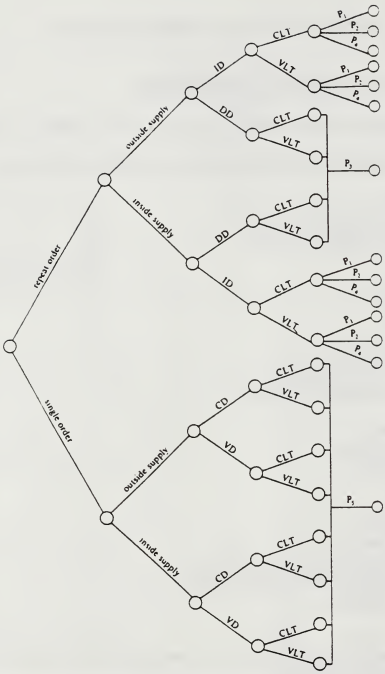


Figure 2. Inventory problem classifications.

DD : dependent demand
ID : independent demand
CD : constant demand
D : variable demand
CLT: constant lead time
VLT: variable lead time

P1: perpetual inventory system
P2: periodic inventory system
P3:material requirements planning
P4: distribution requirements planning
P5: single order quantity system

B. INVENTORY COSTS

Ordering, carrying, shortage, and capacity-associated costs are the parameters which are usually considered in inventory decisions: [Ref. 3]

1. Ordering/processing costs:

Ordering costs include inventory management and contracting personnel salaries, preparing and processing orders, receiving, inspecting, and delivering the materials to store.

2. Carrying/holding costs:

All expenses incurred for holding the volume of inventory on hand, such as: obsolescence, deterioration, insurance, warehouse costs, and opportunity cost of capital invested in the inventory.

3. Shortage costs:

When items are not available for the customer, a special order must be placed which causes expediting costs, lost customers, or at the least, loss of goodwill. Though these costs are difficult to measure, they are important concerning readiness in the military.

4. Capacity-associated costs:

These costs are incurred when it is necessary to increase or decrease capacity. This includes hiring, training, overtime, or idle and layoff costs which are the concerns of manufacturing company.

To accomplish the trade-off among these variable costs, inventory managers must establish an optimal combination which will minimize the overall costs and still provide a relatively high performance.

C. ECONOMIC ORDER QUANTITY (EOQ) MODEL

For simplicity, the EOQ model only emphasizes ordering and carrying costs and is accompanied by the following assumptions:

- Demand is uniform, continuous, and known
- Lead time is constant and known
- Ordering and holding costs are known
- No interaction between items
- No stockouts are permitted
- No quantity discounts
- Unlimited capital expense
- Unlimited storage space
- Infinite time horizon

The holding costs are proportional to the value of the inventory. But the ordering costs are considered fixed and independent from the quantity ordered. [Table. I] When both costs reach the equilibrium point (the holding costs equal to the ordering costs), the total variable costs are minimal. [Figure 3] Because the inventory holding cost rate (I) is fixed, we would like to keep less expensive inventory on hand and order them more often to minimize the TVC.

Total variable costs = ordering costs + holding costs

$$TVC = H (Q / 2) + A (D / Q) = H Q^* = I C Q^*$$

After taking the first derivative with respect to Q, we got

$$Q^* = \sqrt{2 A D / H}$$

TVC: Total variable costs

A : Administrative (Ordering) costs

H : Holding costs per unit which equals to I * C

I : Inventory holding cost rate (average 22% of item cost in the U.S. Navy)

C : Unit cost for an item

D : Demand rate (units per month, quarter or year)

Q : Order quantity (Q^* means optimal order quantity)

D/Q: Frequency of order per year (F = D / Q)

Q/2: Average inventory quantity carried on hand

After determining "how much to order," Q^*, it is important to estimate "when to order." By setting up a reorder point (R), we may track the inventory volume on hand and decide when to process a new order. In the deterministic model, the inventory demand rate (D) and the length of lead time period (L) are known and constant. Therefore, R is simply calculated by D times L.

$$R = D * L$$

D. STATISTICAL CONSIDERATIONS

Instead of describing the normal and Poisson distributions say this: We approximate the demand by the Poisson distribution. For fast moving items this implies using the normal distribution to approximate the Poisson distribution. We will use the Poisson for demand rates of up to 12 items per period. For more than 12 items we use the normal distribution, with mean and variance equal to the demand rate. We also use the normal distribution for the lead time.

E. SAFETY STOCK

Safety stock is extra inventory kept on hand as a buffer against stockout. By providing safety stocks, the variations of demand during lead time are absorbed and most of the time we will have some inventory on hand before the next order arrives. Similar considerations arise concerning the trade-off between reducing additional holding costs and increasing service level. [Fig. 4] In fixed order size systems, the reorder point is composed of the mean lead time (D) plus the safety stock (S). When demand is normally distributed, the reorder point can be expressed as follow:

$$R = \overline{D} + S = \overline{D} + z\sigma$$

R : Reorder point

$\overline{D}$: Average lead time demand

S : Safety stock

z : Value associated with the standard normal distribution

σ : Standard deviation of lead time demand

F. PROBABILITY OF STOCKOUT

In the previous discussion, we assumed that demand and lead time were deterministic. In the real world, these elements do change over time. In the probabilistic models these are random variables[Figure 5], and it is necessary to minimize the expected shortage costs. In discrete cases, a particular demand level is selected which obtains the lowest expected costs.

$$P(D > R) = \sum_{D=R+1}^{Max} P(D) = 1 - \sum_{D=0}^{R} P(D)$$

$$E(D > R) = \sum_{D=R+1}^{Max} (D - R) P(D)$$

D : Lead time demand

R : Reorder point inventory (including safety stock)

P(D) : Probability of lead time demand

P(D>R): Probability of a stockout

E(D>R): Expected quantity of stockout

Max : Maximum lead time demand

G. SHORTAGE COSTS EXPRESSION

When the Navy runs out of certain items, there are no lost sales but rather lack of good service to the customer. Furthermore, in case of urgent needs, some extra expenses are incurred to rush the order and to express-deliver the materials. To prevent this kind of situation, we may want to consider the shortage costs as a parameter and put some "weight" on the critical items against stockout. Therefore, the annual safety

stock costs are the amount of safety stock's holding costs plus the expected shortage costs.

$$TSC = H S + K \{ D / Q [\sum_{M=R+1}^{Max} (D - R) P(D)] \}$$

$$= H (R - D) + K (D / Q) [E(D > R)]$$

$$P(D>R) = P(s) = H Q / K D \quad \text{(Ref. 1)}$$

$$TVC = H Q / 2 + A D / Q + TSC$$

TSC : Total safety stock costs

TVC : Total variable costs

H : Inventory holding cost

S : Safety stock

P(*s*) : Probability of stockout

K : Shortage costs

Max : Maximal lead time demand

P(D) : Probability of a demand during lead time

* An example is given in Table II.

H. SERVICE LEVEL

It is quite difficult to estimate stockout costs in the Navy. An alternate approach is to determine the reorder point based upon the service level. In general, a service

level is the probability that inventory on hand will satisfy demands during the procurement lead time. It may expressed as:

$$SL\ (\%) = 1 - P(s)$$

When the probability distribution of lead time demand is known and the expected service level is determined by inventory manager, we can easily decide how much inventory to order manually. For example, given the empirical demand distribution, and 95% of SL is desired, one must prepare 500 units to meet the requirements.

Service Level Percentage

R	P(X)	P(*s*)	SL (%)
100	.05	.95	5
200	.10	.85	15
300	.35	.50	50
400	.35	.15	85
500	.10	.05	95 *
600	.05	.00	100

R : Reorder point (inventory level)

P(X) : Probability of lead time demand

P(*s*) : Probability of stockout

SL(%): Percentage of demand satisfied during lead time

I. REORDER DECISION

The question of when an order should be placed is very important. Ideologically, we hope that stock replenishment orders are placed over time and material received, prior to depleting the stocks. The EOQ model is used as a fundamental model for solving "When to order" problem. Inventory review systems are classified as follows : [Ref. 3]

1. Continuous Review

a. Q-System

The fixed order size system (Q-system) involves continuous review of inventory levels such that when the item stock level drops below the reorder point (R), a replenishment order is triggered for amount Q. (Figure 6-1)

b. RM-System

This system is a variant of the Q-system. It reviews the stock level continuously and a replenishment order is placed whenever the on hand inventory reaches or falls below the reorder point (R). The replenishment quantity is the amount of the deficit between the reorder point quantity (R) and the on hand quantity (q) at the time the order is placed. (Figure 6-2)

2. Periodic Review

a. P-System

The fixed order interval system (P-system) is a policy where inventory levels are reviewed at a fixed order period (T), and replenishment orders are placed for the difference between a pre-determined maximum level (M) and the amount on hand (q) at the time of review. (Figure 6-3) The P-system control has some advantages:

monitor the stock level less than Q-system, can be scheduled to coordinate joint orders with the review time of other items, allow for purchase economies and lower transportation costs. The major disadvantage for P-system is that this policy carries higher average inventory levels.

b. TRM-System

This system is a variant of the P-system. During the specified review period, if the on hand quantity has reached or dropped below the reorder point (R), an order for the difference between the maximum level (M) and the on hand inventory (q) is placed; if not, do nothing. When the fixed order period is shorter than the lead time period, the stock on hand must include units on order but not yet received. (Figure 6-4)

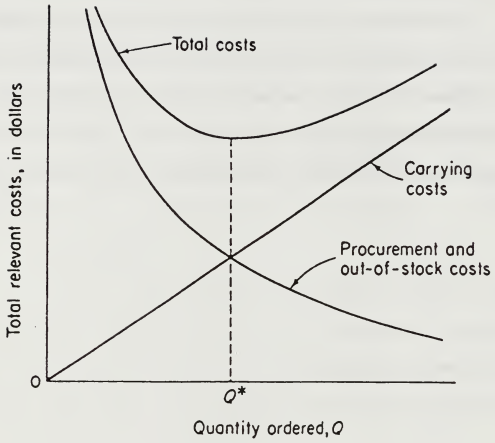


Figure 3. Basic Inventory Cost Trade-offs for a common inventory situation

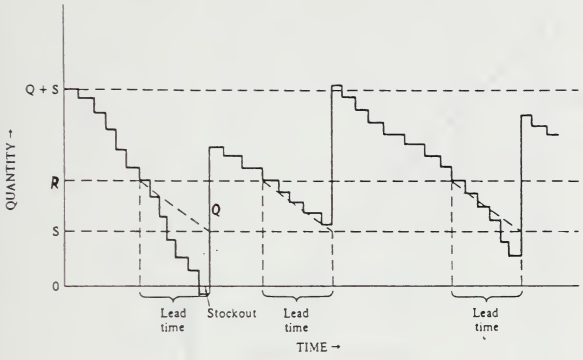


Figure 4. Reorder Point and Safety Stock

R : reorder point

S : safety stock

Q : order quantity

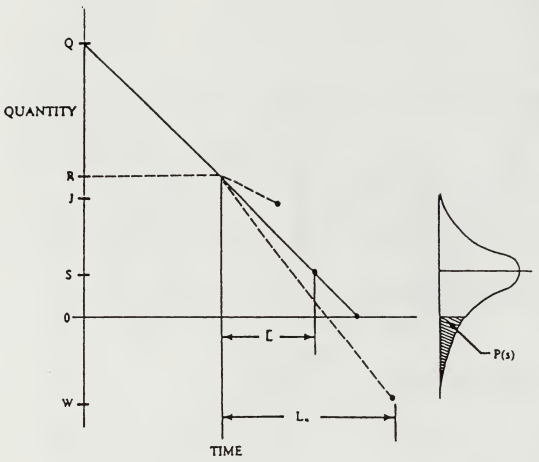


Figure 5. Variable Demand and Variable Lead Time [Ref. 1]

Q : order quantity

R : reorder point

S : safety stock

L_m : maximum lead time

L : expected lead time

P(*s*): probability of stockout

R-S: expected lead time demand

R-W: maximum lead time demand

R-J: minimum lead time demand

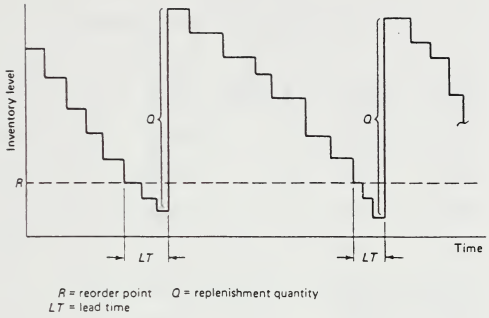


Figure 6-1. Q-System

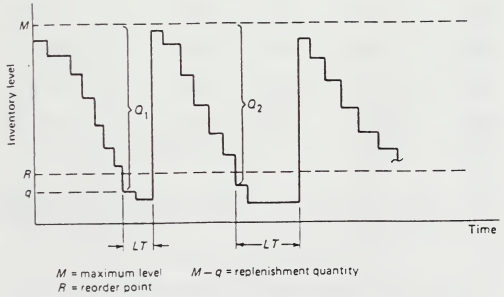


Figure 6-2. RM-System

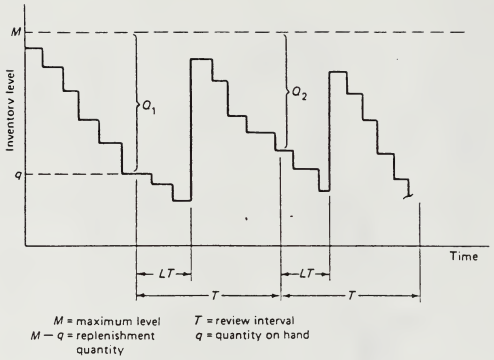


Figure 6-3. P-System

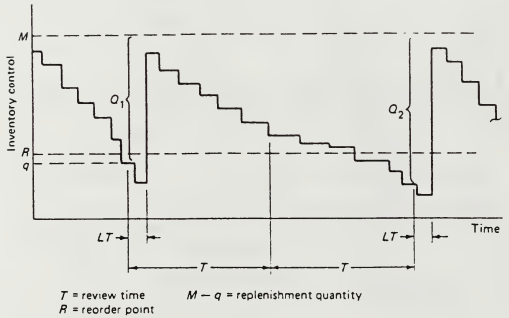


Figure 6-4. TRM-System

TABLE I.

Components of the Total Annual Variable Costs

Size	Freq.	Order Costs	Avg. Inv. On-hand	Carrying Costs	Total Costs
100	60	6000	50	150	6150
120	50	5000	60	180	5180
150	40	4000	75	225	4225
200	30	3000	100	300	3300
300	20	2000	150	450	2450
400	15	1500	200	600	2100
500	12	1200	250	750	1950
600	10	1000	300	900	1900
1000	6	600	500	1500	2100
2000	3	300	1000	3000	3300
3000	2	200	1500	4500	4700
6000	1	100	3000	9000	9100

Assumed: D = 6000 units / year C = $ 15 / unit I = 20 %

A = $ 100 / order H = C * I = $ 3 / unit / year

$Q^* = (2 * 100 * 6000) / 3 = \underline{632 \text{ (units)}}$

TVC = 3 * 632 / 2 + 100 * 6000 / 632 = $\underline{\$ 1897}$

TABLE II.

Total Annual Safety Stock Costs and Stockout Costs

D	P(D)	E(D>R)	Kf	S	Hs	TSC
100	.05	-	-	-	-	-
200	.10	-	-	-	-	-
300	.35	-	-	-	-	-
400	.35	35	3500	100	800	4300
500	.10	20	2000	200	1000	3600
600	.05	15	1500	300	2400	3900

Assumed: $R = 300$ units $F = 4$ orders / year

$H = \$ 8$ / unit / year $K = \$ 25$ / unit

$E(D>R) = (D - R) P(D)$

$Kf = K * F = K * D / Q$

$Hs = H * S$

$TSC = H S + K D / Q [E(D>R)]$

$= Hs + K F [E(D>R)]$

IV. FORECASTING

A. INTRODUCTION

An estimate of future demand for each item is essential to making inventory management decisions. A forecast of demand is necessary in deciding not only when and to what level to replenish materials but also to stock and to dispose of an item. [Ref. 4] Rational decisions still have to be based on some estimate of demand. The strategy used to forecast demand may be so complicated that a computer is needed to solve the sophisticated formulas; or it may be done manually. None of the forecasting methods predict future demand perfectly. The most we can expect from a forecasting method is that it be less inaccurate than pure guessing or other forecasting methods.

After buying weapon systems or equipment, there will be 10-30 years of required supply support to keep them operating efficiently. But when members of congress tend to be more aware of military expenditures, the logistic support budget is probably one of the first to be targeted for reduction. Therefore, to prevent excess inventory positions and still provide sufficient support, more accurate forecasting techniques must be relied upon to maintain reasonable service levels.

B. FORECAST MODELS

1. Moving Average

The first forecast technique is to forecast based on previous demand observations for the item. Usually recent data are more reliable. Hence, the idea of Moving Average is "whatever the demand was in the past few months will most likely

be the demand in the next few months". Moving Average recognizes some degree of trending signal, but would not recognize the seasonal and the cyclical effect of the demand. We may also use the "Weighted" Moving Average which utilizes the mathematical behavior of the Arithmetic or the Geometric weighted average of the historical data.

$$F_n = (\sum D_{n-i}) / t = (D_{n-1} + D_{n-2} + ... + D_{n-t}) / t$$

$$= F_{n-1} + (D_{n-1} - D_{n-t-1}) / t$$

When t = 1 we get Last Period model which is:

$$F_n = D_{n-1} / 1 = D_{n-1}$$

When t = n - 1 we get Simple Average model which is:

$$F_n = (D_{n-1} + D_{n-2} + ... + D_1) / n - 1$$

F_n: Forecast demand for the next period.

D_i: Actual demand in previous months. (D_{n-1} is the most recent one.)

2. Exponential Smoothing (EXSM)

Like most forecasting techniques, EXSM uses historical data as its prediction basis. EXSM is the simplest form for calculating a weighted moving average and it is the most widely used forecasting technique in the world. A model that uses all the data with appropriate weighing (more weight on recent data, and less on older data) should be superior to a model that discards most of the data. The two major

advantages of the EXSM are facilitating computation and reducing data storage space. This means that all the previous data is included in one figure-- "previous forecast", and is the only record that needs to be retained.

The EXSM model forecasts demand level for the next period from the most recent forecasted demand (F_{n-1}) plus a fraction of the error between the actual demand (D_{n-1}) and the forecasted demand (F_{n-1}) for the most recent period. [Table III]

$$F_n = F_{n-1} + \alpha (D_{n-1} - F_{n-1})$$

$$= \alpha D_{n-1} + (1-\alpha) F_{n-1}$$

F_n : Forecast demand for next period

F_{n-1}: Most recent forecast demand

D_{n-1}: Most recent actual demand

α : Exponential constant between 0 and 1

$D_{n-1} - F_{n-1}$: Error between previous forecast and actual demand.

The general formula for exponential smoothing model is as follow:

$$F_n = \alpha [D_{n-1} + D_{n-2}(1-\alpha) + D_{n-3}(1-\alpha)^2 + ... + D_{n-k}(1-\alpha)^{n-1}] + (1-\alpha)^n F_0$$

$$= \alpha [\sum_{K=1}^{n}(1-\alpha)^{k-1} D_{n-k}] + (1-\alpha)^n F_0$$

F_n : Forecast demand for next period

F_0 : The initial forecast number

D_{n-1}: Actual demand in last period

D_{n-k}: Actual demand in previous (when K=1 is most recent data)

a : Exponential smoothing constant between 0 and 1

3. EXSM With Trend Correction

The EXSM model provides an adequate forecast for the future if no trend, seasonal, or cyclical effects exist. The cyclical effect needs to consider long term historic data (at least three years). However only two years of data are maintained in the ROC Navy's inventory management system. Two kinds of filters may be set up for testing trend and seasonal effects in forecasting procedures.

$$F_n = a\,D_{n-1} + (1-a)\,(F_{n-1} + T_{n-1}) = a\,D_{n-1} + (1-a)\,Y_{n-1}$$

$$T_n = b\,(F_n - F_{n-1}) + (1-b)\,T_{n-1}$$

$$Y_n = F_n + T_n$$

F_n : Simple forecast demand for next period

F_{n-1}: The most recent forecast demand

D_{n-1}: The most recent actual demand

T_n : Trend signal

T_{n-1}: The most recent trend signal

a,b : Exponential constant between 0 and 1

Y_n : The forecast demand after trend correction

Y_{n-1}: Last period forecast demand

4. EXSM With Seasonal Correction

Seasonal effects due to weather-related conditions or products, and/or the arrangement of maintenance schedules in the Navy, particularly the demand frequency,

follow the same pattern year after year. To set up a seasonal correction filter, at least a 2-year pattern of previous demand must be compared. To accomplish this, monthly seasonal index numbers must be computed. The seasonal index numbers represent the expected ratio of demand in each month to the average demand per month. [Table IV] The computation procedures are as follows:

1. Determine seasonality indices from previous data (I_n) for period n.

$$I_n = I_i / I_{AVG}$$

* Or we may smooth the $I_n = c\ (\ F_{n-1} / D_{n-1}\ ) + (1-c)\ I_{n-1}$ exponentially.

2. Deseasonalize demand to get forecast level

$$F_n = a\ (\ D_{n-1} / I_{n-1}\ ) + (1-a)\ F_{n-1}$$

3. Compute seasonalized forecast

$$Y_n = F_n * I_n$$

5. Formulas for the EXSM with Trend and Seasonality Correction

$$F_n = a\ [\ D_{n-1} / I_{n-1}\ ] + (1-a)\ [\ F_{n-1} + T_{n-1}\ ]$$

$$T_n = b\ (\ F_n - F_{n-1}\ ) + (1-b)\ T_{n-1}$$

$$Y_n = (\ F_n + T_n\ )\ I_n$$

By a trial method in the computer program, we can get a best smoothing constant to analyze the historic data, and to predict the future demand. It is also possible to apply the historical demand behavior and experimentation of the data into EXSM. (Figure 7-1 and 7-2)

C. FORECAST ERROR

The difference between the actual values (D_i) and the predicted values (F_i) are defined as forecast error. When each forecast technique is tested on historical data, the one with the smallest forecast error is the one we would like to select as the forecast instrument. Based on the forecast error, we may select a better forecast technique and may evaluate the success or failure of a model. There are two types of useful forecast errors, "Mean Absolute Deviation (MAD)" and "Bias". MAD expresses the extent of the forecast error and Bias indicates the direction of the forecast error. Both are introduced as follows:

1. MAD

The MAD is the average variance between the actual data and the forecast data, and ignores the positive or negative sign.

$$MAD = \sum \left| D_i - F_i \right| / n$$

For the EXSM is:

$$MAD_{Pn} = a \left| D_{n-1} - F_{n-1} \right| + (1-a)\, MAD_{Pn-1}$$

2. Bias

A positive bias indicates the tendency to underforecast, while a negative bias indicates a tendency to overforecast.

$$Bias = \sum (D_i - F_i) / n$$

The statistic of forecast error is needed: (1) to judge the suitability and adequacy of a particular forecast model, (2) to provide information for adjusting estimates of forecast model parameters, and (3) to set service levels on products provided to customers [Ref. 1]. The choice of the most desirable forecast technique is the one with the smallest MAD or Bias.

D. FORECAST DEMAND AND MAD_n

At the end of a month (quarter or year), the actual demand (D_{n-1}) for the month is calculated. We had the previous forecast number (F_{n-1}), the mean absolute deviation of demand (MAD_{n-1}), the observed procurement lead time (PCLT), and the mean absolute deviation of PCLT (MAD_{LT}) from last month. Using these data, we may forecast the demand and lead time for the next month. The following procedures are based on the current U.S. Navy "Wholesale Requirements Determination" [Ref. 5] model for calculating consumable items (Mark II item) with some modifications. This model uses single simple exponential smoothing in the forecasting method.

1. Filter the observation D_{n-1} to see if the D_{n-1} is outrageous. Set up a range of three standard deviations for a normal distribution (σ = 1.25MAD). Normally 99.7% of the demand will fall within the filter.

$$(F_{n-1} - 1.25\ MAD_{n-1} * 3) \leq D_{n-1} \leq (F_{n-1} + 1.25\ MAD_{n-1} * 3)$$

2. If D_{n-1} is "within filter", perform the trend test. Else, let $D_{n-1}=D_n$.

   a. Compute $T = \dfrac{2 (D_{n-1} + D_{n-2})}{D_{n-1} + D_{n-2} + D_{n-3} + D_{n-4}}$ (quarterly demand)

b. When $0.8 \leq T \leq 1.2$ use a= 0.2, otherwise a= 0.4 (more weight in recent data to catch up with lagging.) ($0.99 \leq T \geq 1.5$ for expensive items to reduce the demand noise.)

c. When T was out of filter : if trend direction of D_{n-1} opposite to D_{n-1}, set a = 0 ($F_n = F_{n-1}$, $MAD_n = MAD_{n-1}$); if their were the same, set Fn = $(D_{n-1} + D_{n-2}) / 2$ and $MAD_n = 1.518\ (F_n)^{817}$

3. Compute forecasts:

$$F_n = a\ D_{n-1} + (1-a)\ F_{n-1}$$

$$MAD_{Dn} = a\left|F_{n-1} - D_{n-1}\right| + (1-a)\ MAD_{Dn-1}$$

E. FORECAST PROCUREMENT LEAD TIME(PCLT) AND MAD_{LT}

The procurement lead time is divided into two parts: administrative lead time (ALT) and production lead time (PLT). The time interval of ALT includes preparing an order, negotiating with the contractor, delivering, receiving, and storing materials. The information of PLT is obtained from the vendors.

1. Filter the observed PCLT measured in days (symbolized by W):

$$0.5\ (\overline{W}_{n-2}) < W_i < 2\ (\overline{W}_{n-2})$$

If the observation (W_i) is within the filter, we keep it; if out of filter, the Item Manager chooses whether to keep the observation or not.

2. Compute forecasts (PCLT and MAD_{LT})

a. Compute mean of observed PCLTs and convert to month.

$$\overline{W}_{n-1} = [\ (\ W_{i1} + W_{i2} + ... + W_{im}\ )\ /\ m\ ]\ /\ 30$$

b. EXSM forecasts.

$$\hat{W}_n = c\ \overline{W}_{n-1} + (1\text{-}c)\ \hat{W}_{n-1}$$

c. Forecast MAD_{W_n}

$$MAD_{W_n} = c \left| \overline{W}_{n-1} - \hat{W}_{n-1} \right| + (1\text{-}c)\ MAD_{W_{n-1}}$$

F. COMPUTE THE CONSTRAINED $\hat{Q}$ AND $\hat{R}$

1. Compute $Q^* = \sqrt{2\ D\ A\ /\ I\ C}$
2. Compute $\tilde{Q} = \min\ \{\ 3\ D,\ \max\ \{\ K_o\ D,\ 1\ ,\ Q^*\ \}$
3. Compute Risk $= \dfrac{D\ I\ C}{D\ I\ C + \lambda\ F\ E}$
4. Compute $\widehat{Risk}$ = min { max allowable risk (0.5), max { Risk, min allowable risk (0.1) }
5. Obtain "z" from normal distribution table which corresponds to Risk
6. Compute $\sigma^2 = \hat{W}_n\ \{\ (\ 1.25\ MAD_{D_n}\ )^2 + D^2\ \}$ or,

   $\sigma^2 = (2.028\ D_{LT}^{.701})^2$
7. Compute $R^* = D\ \hat{W}_n + z\ \sigma^2$
8. Compute the constrained $\hat{R}$:

$R = \max\ \{\ 0,\ NSO,\ \min\ \{\ (\ 4\ D\ H + D\ \hat{W}_n - K_o\ D\ ),\ \max\ \{\ R^*,\ PY\ \}\}$

9. Compute the constrained $\hat{Q}$:

$\hat{Q} = \min \{ Q, \{ 4 D H - \max [0, (\hat{R} - D \hat{W}_a)] \} \}$

Q^* : Basic EOQ

$\tilde{Q}$: Required minimum order quantity

D : Annual demand rate

3D : Maximum inventory on hand (3 years demand)

K_o : Pre-set minimum order quantity for attrition demand factor

Risk: Probability of stockout

IC : Inventory holding cost (H=IC)

λ : Shortage cost of one requisition backordered for one year

F : Procurement frequency

E : Military essentiality

Risk: Constrained risk rate (max risk is to limit the probability of stockout; min risk is to keep safety stock on a reasonable level)

z : Risk factor associated with the standard normal distribution

σ^2 : Variance of procurement problem variable

R^* : Reorder level (includes safety stock)

NSO : Numeric stockage objective

PY : Policy receivers

$\hat{R}$: Constrained reorder point

$\hat{Q}$: Constrained order quantity

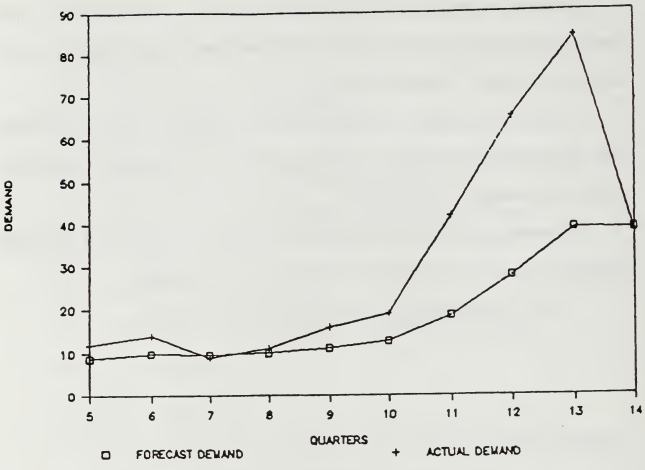
H : Shelf life

These models determine the optimum order quantity and reorder level for an item based on that item's forecasted quarterly demand rate, procurement lead time, forecast error, and unit price. We also need to:

1. Calculate the parameters needed for using the technique, included in the Master Data File (MDF) for each item, so that they can be given to procurement personnel when a replenishment order is needed.

2. Develop procedures for providing the procurement personnel with the additional information and computing equipment needed to use the technique.

3. Train procurement personnel in the use of the technique.

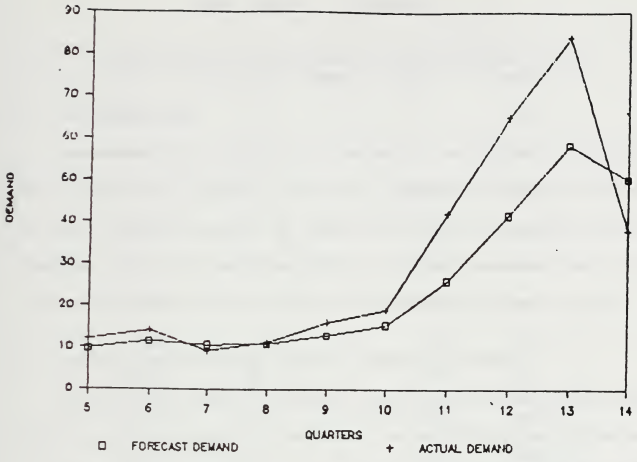


Qtr	Observed Demand	Absolute Deviation	Forecasted Demand	Forecasted MAD	Trend Value
5	12	4.000	8.800	2.400	
6	14	5.200	9.840	2.960	
7	9	0.840	9.672	2.536	0.870
8	11	1.328	9.938	2.294	1.080
9	16	6.062	11.150	3.048	1.273
10	19	7.850	12.720	4.008	1.386
11	42	29.280	18.576	9.063	1.507
12	65	46.424	27.861	16.535	1.419
13	84	56.139	39.089	24.456	1.066
14	38	1.089	38.871	19.782	0.406
		158.212			

Figure 7-1. COMPARISON OF DEMANDS

$F_0 = 8$ $MAD_0 = 2$ $a = 0.2$ $1 - a = 0.8$

Actual $MAD_n = 158.212 / 10 = 15.8212$



Qtr	Observed Demand	Absolute Deviation	Forecasted Demand	Forecasted MAD	Trend Value
5	12	4.000	9.600	2.800	
6	14	4.400	11.360	3.440	
7	9	2.360	10.416	3.008	0.870
8	11	0.584	10.650	2.038	1.080
9	16	5.350	12.790	3.363	1.273
10	19	6.210	15.274	4.502	1.386
11	42	26.726	25.964	13.392	1.507
12	65	39.036	41.579	23.649	1.419
13	84	42.421	58.547	31.158	1.066
14	38	20.547	50.328	26.914	0.406
		151.635			

Figure 7-2. COMPARISON OF DEMANDS

$F_0 = 8$ $MAD_0 = 2$ $a = 0.4$ $1 - a = 0.6$

Actual $MAD_0 = 151.635 / 10 = 15.1635$

TABLE III. Seasonal Index

Month	1988	1989	2-yr Avg.	S/I
Jan	7	5	6	0.30
Feb	9	7	8	0.40
Mar	29	31	30	1.50
Apr	33	37	35	1.75
May	30	32	31	1.55
Jun	12	14	13	0.65
Jul	12	10	11	0.55
Aug	8	12	10	0.50
Sep	28	30	29	1.45
Oct	33	35	34	1.70
Nor	27	25	26	1.30
Dec	8	6	7	0.35

Avg = 240 X = 20

S/I = Avg / X

V. PERFORMANCE MEASURES OF EFFECTIVENESS (MOEs)

A. INTRODUCTION

Measurements of the supply system performance are very important. But because the ROC Navy lacks knowledge in the technical approaches and concepts of MOEs, we cannot reasonably measure the performance of the over-all supply system. Therefore, setting up the criteria for the MOEs may help to determine and review how well the supply system performs and what is the reliability of our weapon systems.

B. GROSS EFFECTIVENESS AND NET EFFECTIVENESS

The gross effectiveness (GE) is measured by the percent of total requisitions (both stocked and non-stocked items) that are received and satisfied from stock on hand at any given level of inventory. It is mainly used by the stock points and the retail consumer level supply departments as a measure of customer service.

$$GE(\%) = \frac{\text{\# of requisitions filled}}{\text{\# of total requisitions}}$$

or,

$$= \frac{\text{\# of units issued}}{\text{\# of units requested}}$$

The net effectiveness (NE) is measured by the percent of total requisitions received and satisfied from stock on hand for stocked items only.

$$NE(\%) = \frac{\text{\# of requisitions filled}}{\text{\# of total requisitions}} \quad \text{(for stocked items only)}$$

I. SYSTEM MATERIAL AVAILABILITY (SMA)

System material availability (SMA), a customer service measure at the wholesale level, is defined as the percent of requisitions satisfied on the first pass. It is prepared monthly by a Uniformed Inventory Control Point (UICP) program. [Ref. 5] The current wholesale SMA goal for the U.S. Navy is 85 percent. It is computed as follow:

$$SMA\ (\%) = 100 * [\ 1.0 - (\ BO + DVD\ ) / D\ ]$$

or,

$$= 100 * [\ 1.0 - MOE / D\ ]$$

BO : Backorders established

DVD : Direct vendor deliveries established

D : Demand

MOE : Material obligations established (*MOE* = BO + DVD)

J. OPERATIONAL AVAILABILITY (Ao)

The effectiveness of a weapon system depends on its ability to perform a military mission and to continually operate for a specified period of time. Operational availability (Ao) is the average time that the equipment is in operable condition. It is interpreted as the probability that a system or equipment, when used under stated conditions in an actual operational environment, will operate satisfactorily when called upon. [Ref. 6] Ao is used to measure weapon system readiness and reliability, and to provide an indicator of hardware, fleet and total supply system performance. The implementations of Ao in the U.S. Navy are: Casualty Reports (CASPEPS), Not

Mission Capable Supply (NMCS), Partially Mission Capable Supply (PMCS), and Maintenance & Material Management (3M) data. Eventually, Ao may be incorporated in some inventory requirements determination models.

It is expressed as:

$$Ao = \text{UP TIME} / \text{TOTAL TIME}$$
$$= \text{UP TIME} / (\text{UP TIME} + \text{DOWN TIME})$$
$$= \text{MTBM} / (\text{MTBM} + \text{MDT})$$
$$= \text{MTBF} / (\text{MTBF} + \text{MTTR} + \text{MSRT})$$

MTBM: Mean time between maintenance

MDT : Mean maintenance downtime

MTBF: Mean time between failures (measure of reliability)

MTTR: Mean time to repair (measure of maintainability, when all needed repair parts are available)

MSRT: Mean supply response time (measure of supply support posture)

E. MEAN SUPPLY RESPONSE TIME (MSRT)

From the operational availability (Ao) formula, we may observe that any reduction in the mean supply response time (MSRT) will increase Ao. MSRT is the average time required by the supply system in order to satisfy demands at the wholesale level. It is measured from the time a requisition generated at the stock point until the material is actually received at the stock point. MSRT is basically used for wholesale level provisioning and wholesale requirements determination in the U.S. Navy.

MSRT = TWUS / D

TWUS: Time weighted units short

D : Mean demand

By considering the item's essentiality into the MSRT process of wholesale requirement determination, we can provide a more efficient tool for budget development, and also focus on the most important items that we need.

L. AVERAGE CUSTOMER WAIT TIME (ACWT)

Average customer wait time (ACWT) is a primary performance measure linking supply responsiveness to operational requirements. It represents the average time required in the supply system to satisfy maintenance related demands. ACWT is a collective goal for supply system response time for all customer demands, as measured from requisition generation until receipt of the material by the customer, including requisition submission and receipt take-up times.

The current ACWT goal for continental U.S. customers is 125 hours for items in issue priority groups I and II (the most critical requisitions). The achievement of this goal depends on the integration of these variables: requisition processing and material handling time, and the gross availability at the consumer, intermediate, and wholesale levels. The expected maximum requirement time for each level is shown in Figure 8.

* A numerical example is given in Table V.

TABLE V.

Requisition size (units)	Delay time	Julian date submitted	Julian date received
3	3	020	023
5	0	058	058
2	2	062	064
8	5	083	088
4	1	099	100
*2	90	103	193
1	3	104	107
2	12	118	130
6	0	131	131
7	1	159	160
40	77		

* Non-stocked item

GE = 2 / 10 = 0.2 = 20 %

NE = 1 / 9 = 0.111 = 11.1 %

MSRT = (3 * 3 + 5 * 0 + ... + 7 * 1) / 40

= 271 / 40 = 6.775 (days)

ACWT = (3 + 0 + 2 + ... + 7) / 10

= 117 / 10 = 11.7 (days) = 280.8 (hours)

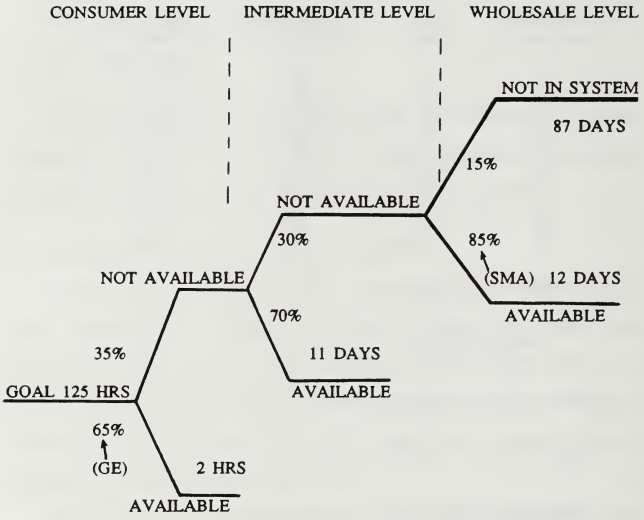


Figure 8 AVERAGE CUSTOMER WAIT TIME (IPG I AND II REQUIREMENTS)

VI. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The objectives of this thesis are to analyze the ROC Navy's inventory models, suggest possible improvements, and recommend appropriate changes in order to further improve the inventory management process and overall supply support performance. The two primary operating doctrines of basic inventory management are: "How much to order" and "When to order". By formalizing the concept of inventory behaviors into mathematical models, we are able to simplify realistic inventory situations and solve inventory problems. The desired benefits of this thesis would be to improve a fundamental inventory management system, and to relieve some inventory control problems in the ROC Navy.

In the EOQ model, total annual costs are minimized when the holding costs and ordering costs are equal. In the probabilistic model, holding costs (for both regular demand requirements and safety stocks on hand), and stockout costs must be balanced to get the minimum total annual costs. The advanced inventory models determine the optimal order quantity and reorder level for an item based on that item's forecasted demand rate and procurement lead time. These inventory management techniques and forecasting models may be used in conjunction with models currently used by the ROC Navy to improve inventory management. Through the application of computer programs, these techniques can be performed efficiently and effectively.

Implementing the MOEs would provide guidelines to measure the availability and readiness of the ROC Naval supply system and weapon systems. In order to achieve a higher operating goal, the MOE principles must be used continuously to monitor the system performance.

B. CONCLUSIONS

Inventory management is a complicated and difficult task. But the implementation of scientific inventory models would make this task much easier and allow inventory managers to become more proficient. Therefore, it is very important to introduce the concepts and advantages of scientific inventory approach to inventory managers. Implementing the appropriate inventory models would reduce total inventory costs. Developing well organized inventory policies would improve the overall supply system performance. Thus, we need to:

- Use the forecasting models for determining demand and procurement lead time.
- Quantify the various costs needed by these models.
- Program the computation process for generating the optimal order quantities and reorder points.

By adopting the consumable model first, the ROC Navy could gain valuable practice and experiences in using new models. It would then be appropriate and easier to develop models for slow moving items and repairable items.

C. RECOMMENDATIONS

Some recommendations for the ROC Navy:

1. Establish data files for weapon systems, equipment and parts. Include in the data files the following information: the unit price, PCLT, supply sources, processing costs, holding costs, shortage costs, and item essentiality. These data are necessary to be able to fully implement the advanced inventory techniques.

2. Train all personnel who will be involved with these techniques, to ensure that they are highly motivated, and capable to solve the existing inventory problems.

3. Adjust supply demand review (SDR) schedule as follow: reduce inventory managers workload by treating fast, medium, and slow movers differently. The author suggests this schedule: review fast movers monthly and procure them quarterly; review medium movers quarterly and procure them semi-annually; review slow movers semi-annually and procure them annually or longer.

In addition to the recommendations above, which are direct conclusions of the thesis, I also recommend the following:

4. Reduce the procurement lead time to minimize holding costs and reduce paperwork.

5. Implement the concepts of just-in-time (JIT) system and material requirement planning (MRP) system to help design the program support requirements.

6. Maintain long term relationships with contractors to assure the continuity of supply.

7. Review existing transportation and material handling techniques for improving inventory management efficiency.

8. Improve warehouse conditions and storage equipment.

9. Introduce the automatic identification system (bar coding) and provide an on-line supervisory control system to reduce both the workload and the possibility of human error.

10. Increase the number of personnel trained in operations research. Design better training programs for contracting and inventory management personnel.

11. Consult the experts prior to implementing or establishing any new inventory techniques.

12. Speed the development of our own weapon systems and equipment, and reduce the dependency on foreign countries.

LIST OF ABBREVIATIONS

A : Administrative (Ordering) costs

C : Unit cost for an item

D : Demand rate (units per month, quarter or year)

E : Military essentiality

F : Procurement frequency

H : Holding costs per unit which equals to I * C

H : Shelf life

I : Inventory holding cost rate (average 22% of item cost in the U.S. Navy)

K : Shortage costs

K_o : Pre-set minimum order quantity for attrition demand factor

Q : Order quantity (Q^* means optimal order quantity)

$\hat{Q}$: Constrained order quantity

R : Reorder point

$\hat{R}$: Constrained reorder point

R^* : Reorder level (includes safety stock)

S : Safety stock

z : Value associated with the standard normal distribution or

Risk factor associated with the standard normal distribution

σ : Standard deviation of lead time demand

σ^2 : Variance of procurement problem variable

λ : Shortage cost of one requisition backordered for one year

D_i : Actual demand in previous months. (D_{n-1} is the most recent one.)

F_0 : The initial forecast number

F_n : Forecast demand for next period

T_n : Trend signal

Y_n : The forecast demand after trend correction

D_{n-1} : Most recent actual demand

D_{n-k} : Actual demand in previous (when K=1 is most recent data)

F_{n-1} : Most recent forecast demand

T_{n-1} : The most recent trend signal

Y_{n-1} : Last period forecast demand

$D_{n-1} - F_{n-1}$: Error between previous forecast and actual demand.

a,b,c : Exponential constant between 0 and 1

3D : Maximum inventory on hand (3 years demand)

BO : Backorders established

PY : Policy receivers

D/Q : Frequency of order per year (F = D / Q)

Q/2 : Average inventory quantity carried on hand

TVC: Total variable costs

TSC : Total safety stock costs

Max : Maximum lead time demand

NSO: Numeric stockage objective

P(D) : Probability of lead time demand

P(*s*) : Probability of stockout

P(X) : Probability of lead time demand

SL(%) : Percentage of demand satisfied during lead time

P(D>R) : Probability of a stockout

E(D>R) : Expected quantity of stockout

$\widehat{\text{Risk}}$: Constrained risk rate

Risk : Probability of stockout

DVD : Direct vendor deliveries established

MDT : Mean maintenance downtime

MOE : Material obligations established

MOEs : Measures of effectiveness

MTBM : Mean time between maintenance

MTBF : Mean time between failures (measure of reliability)

MSRT : Mean supply response time (measure of supply support posture)

TWUS : Time weighted units short

MTTR : Mean time to repair (measure of maintainability, when all needed repair parts are available)

LIST OF REFERENCES

1. Tersine, R.C., Principles of Inventory and Material Management, North-Holland, New York. 1988.

2. Plossl G.W. and Wight O.W., Production and Inventory Control, Prentice-Hall, New Jersey. 1967.

3. Ballou, R.H., Business Logistics Management Planning and Control, Prentice-Hall, New Jersey. 1985.

4. Prichard, J.W., and Eagle, R.H., Modern Inventory Management John Wiley and Sons, New York. 1965.

5. Naval Supply Systems Command Publication 553, Inventory Management, 1988.

6. Blanchard, B.S., Logistics Engineering and Management, Prentice-Hall, New Jersey. 1988.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Department Chairman, Code 54 Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5004	1
4.	Professor Dan Trietsch, Code 54TR Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5004	1
5.	Professor Cynthia Dresser, Code 54DR Department of Administrative Sciences Naval Postgraduate School Monterey, California 93943-5004	1
6.	Cheng, Cheng-Wen No. 14 Alley 3 Lane 172 Cheng Kung RD. Sin Chu, 30016 TAIWAN, R.O.C.	5

615-584

Thesis
C4152
c.1

Cheng
Basic inventory management techniques for the Republic of China.

thesC4152
Basic inventory management techniques fo
3 2768 000 87738 5
DUDLEY KNOX LIBRARY